Breakthrough

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High Performance Steel Produces Durable and Economical Girders

Business Issue

High Performance Steel (HPS) can lower the weight and price of bridge girders. However, the Missouri Department of Transportation had only limited design experience using HPS on one test bridge. MoDOT needed to explore how it could take advantage of HPS girders without sacrificing strength, durability or economical designs.

Figure 1. Bridge A6101

Background

High Performance Steel, in particular HPS70W, has been used in hundreds of bridges across the United States. A large percentage of these bridges have used the HPS in hybrid girder designs. Bridge studies have shown that the most beneficial use of HPS70W (70 ksi) is in the flanges of hybrid girders with 50-ksi webs. MoDOT built the state's first HPS bridge in 2002 as part of the Federal Highway Administration's Innovative Bridge Research and Construction program.

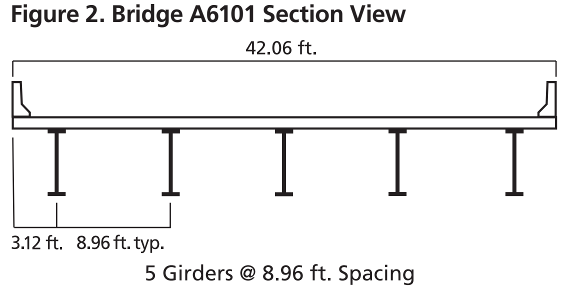
Table 1.
Weight and Material Cost of Homogenous 50 ksi and Hybrid 50/70 Girders

	50 ksi Weight (tons/girder)	50 ksi Cost ($/girder)	HPS70W Weight (tons/girder)	HPS70W Cost ($/girder)	**Total Weight (tons/girder)**	**Total Cost ($/girder)**
Homogenous 50 ksi	34.66	83184	0	0	**34.66**	**$83,184,00**
Hybrid 50/70	22.37	53688	6.5	20280	**28.87**	**$73,968.00**

Assumed In-Place Unit Cost	
50 ksi	$2,400/ton
HPS70W	$3,120/ton

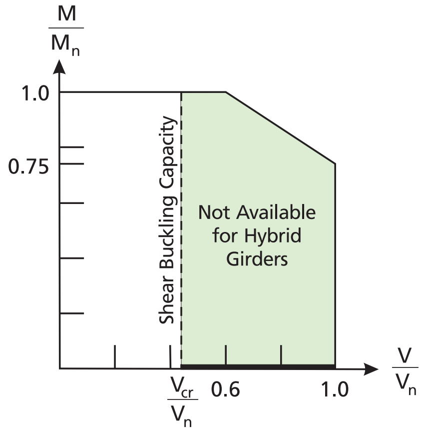
MoDOT Bridge A6101 uses HPS70W (Fy = 70 ksi) in the design of the 138 ft – 138 ft. two-span, five-girder bridge. Design calculations show that using HPS only in the highly stressed regions led to a superstructure steel weight savings of nearly 17 percent and an estimated cost savings of approximately 11 percent compared to a conventional 50 ksi bridge. Figure 2 illustrates the section of Bridge A6101.

Figure 2. Bridge A6101 Section View



However, one limit with hybrid girder design, which decreases the beneficial aspects, is not allowing tension field action (TFA) when determining the shear capacity. This is a severe shear capacity penalty for using hybrid girders as shown in Figure 3. Limiting hybrid shear capacities to the shear buckling capacity, results in more transverse stiffeners required (closer spacing) for a hybrid girder than that for a homogeneous girder. This not only increases material costs, but also significantly increases fabrication costs.

Figure 3. Hybrid Girder Moment-Shear Interaction Restriction



Note: V_n represents shear capacity of TFA applicable
Note: Shear buckling capacity varies with girder dimensions

Approach

MoDOT teamed with the University of Missouri-Columbia to conduct two studies. The first study [1] sought to validate the tension field action behavior in hybrid plate girders. The work conducted for this research covers several topics in tension field action and moment-shear interaction of plate girders.

This was the first effort concentrated on the original shear capacity theoretical derivations and the differences in using hybrid girders. In addition, two series of tests were designed and tested to determine the hybrid girder shear capacity and study the tension field behavior of homogeneous and hybrid girders. Series I test specimens were homogeneous and hybrid girders tested under high shear and low moment conditions. Series II test specimens were hybrid girders designed and tested to study the effect of moment-shear interaction. Figure 4 illustrates the girder section and the test procedures for the Series I tests. Finally, an array of practical bridge designs was developed to study the benefit of allowing TFA in hybrid girders.

Figure 5. Series II Specimen Failed in Shear

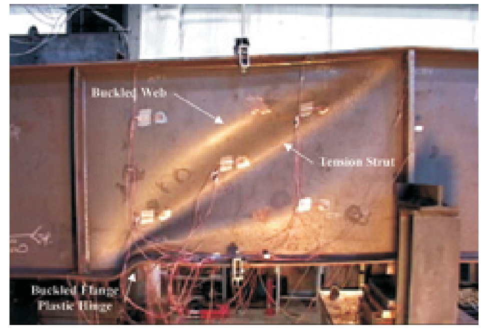
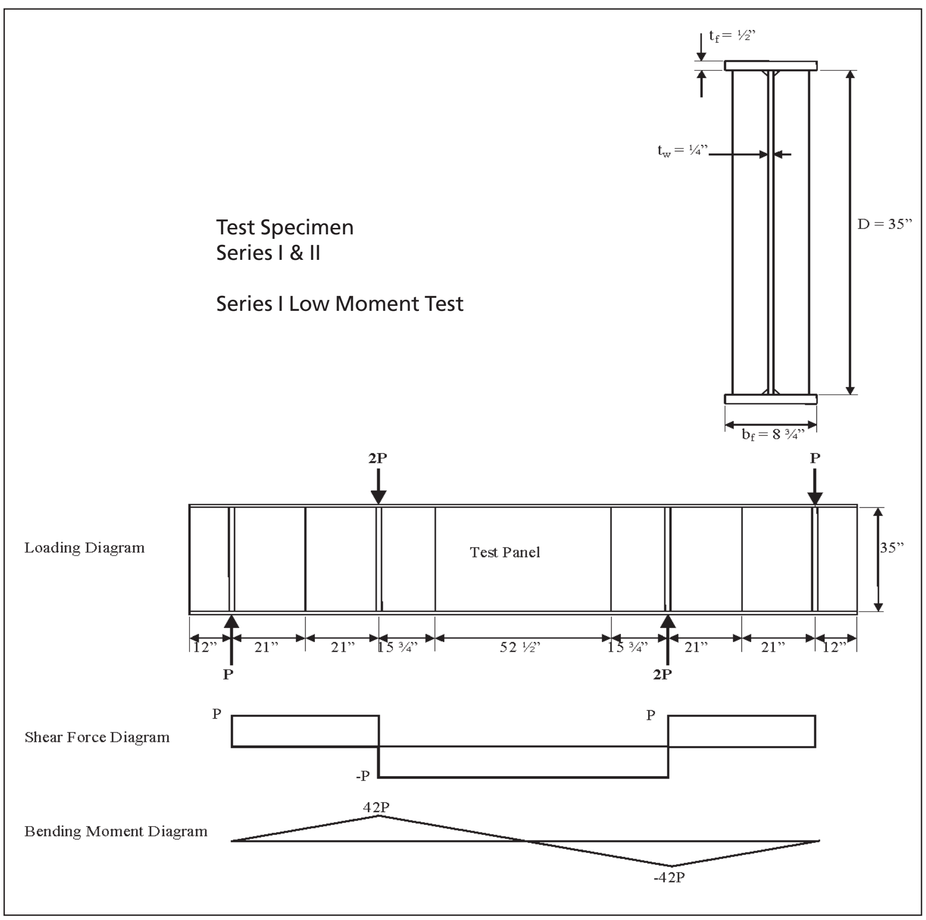


Figure 4. Specimen and Series I Test Set Up



The second study [2] focused on instrumenting, field testing, analyzing, and evaluating the performance of Bridge A6101. The tests concentrated on strength and serviceability behavior of the structure. The University of West Virginia also modeled this bridge using ABAQUS Finite Element Software.

One objective of this research was to examine deflection serviceability limits. MoDOT uses more conservative deflection criteria than the AASHTO Bridge Specifications. This may lead to more conservative designs in Missouri than AASHTO requires. The other objective was to perform field tests to confirm strength performance. The work involved comparing design capacities to equivalent experimental design capacities.

[1] Barker, Dr. Michael, University of Missouri-Columbia, (2005). Shear Tests of High Performance Steel Hybrid Girders. Report OR 06-001, Missouri Department of Transportation, Jefferson City, MO, USA.

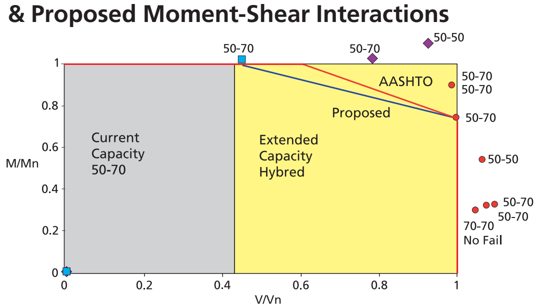
[2] Barker, Dr. Michael, University of Missouri-Columbia, (2005). Performance and Serviceability of HPS Girders, MO 224, Lafayette County. Report OR 06-002, Missouri Department of Transportation, Jefferson City, MO, USA.

Conclusions and Recommendations

■ **Hybrid steel girders exhibit tension field action according to current AASHTO shear capacity provisions**. Using the original moment-shear interaction derivations, this research has produced a theoretical lower-bound moment-shear interaction equation for hybrid girders that is equivalent to the current AASHTO moment-shear interaction requirement for homogeneous girders.

■ **Experimental tests and analytical studies have shown there is no moment-shear interaction for these plate girders.** The girders all demonstrated that the capacities exceeded expectations and that a moment-shear interaction reduction is not necessary. Figure 6 shows the test results, the lower bound moment-shear interaction for hybrid girders plotted against the AASHTO moment-shear interaction diagram.

Figure 6. Test Results Compared to AASHTO & Proposed Moment-Shear Interactions



■ **The serviceability field testing of Bridge A6101 confirmed MoDOT deflection criteria as conservative.** For Bridge A6101 in Table 2, MoDOT predicts a deflection 47% higher than AASHTO while allowing 20 percent less deflection. Bridge A6101 meets the AASHTO deflection criteria but not the MoDOT (a design exception was required to build Bridge A6101). In effect, the bridge would need to possess 87 percent more stiffness than an AASHTO design to meet current MoDOT deflection criteria. The maximum measured deflections for an equivalent HS20 loading match closely to the AASHTO method of estimating deflections. The MoDOT approach significantly over-estimates the measured deflections.

Table 2. Bridge A6101 Deflection Comparison of MoDOT and AASHTO Criteria

	MoDOT Deflection Criteria	AASHTO Deflection Criteria
Design Deflection (inches)	2.30	1.57
Allowed Deflection (inches)	1.65	2.07
Design Deflection/Allowed Deflection	1.39 (NOT OK)	0.76 (OK)
Equivalent Maximum Measured Deflection (inches)	1.85	1.58
Design Deflection/Measured Deflection	1.24	0.99

■ **Bridge A6101 exhibited additional capacity over the design prediction.** While the experimental results showed that the design procedures are conservative for interior girders, they also show that the procedures may be unconservative for exterior girders. The experimental results were confirmed with finite element analyses.

Table 3. Design and Experimental HPS Capacities

	HS Loading Capacity	
	Exterior Girder	Interior Girder
Experimental	HS26.2	HS37.2
Design	HS28.8	HS23.8
Experimental/Design	0.91	1.56

The strength performance field-testing involved comparing design capacities to equivalent experimental design capacities. For design, the minimum design capacity is an HS23.8 truck loading controlled by the positive moment region of an interior girder. The critical experimental design capacity is an HS26.2 controlled by the positive moment region of an exterior girder.

■ **Change MoDOT design specifications for HPS girders.** This and similar work from Georgia Tech were presented to the AASHTO T14 Steel Bridge Committee and to the American Institute of Steel Construction. AASHTO has adopted the recommendation to apply tension field action to hybrid girders. The change has been incorporated into the 3rd Edition of the AASHTO (2004) LRFD bridge specification. Both the 2004 AASHTO and the 2005 AISC building specification have also adopted the recommendation that there is no moment-shear interaction reduction of strength for girders.

For More Information

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